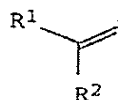
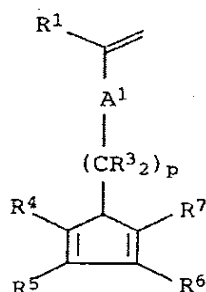


The present invention relates to a supported catalyst for olefin  
5 polymerization comprising

10       where the monomer units I have the formula (I) and the  
monomer units II have the formula (II),



(I)



(II)

45 R<sup>4</sup> to R<sup>7</sup> are hydrogen, C<sub>1</sub>-C<sub>10</sub>-alkyl or substituted or  
unsubstituted phenyl,

and the monomer units III have polar groups,

and

5 B) at least one metallocene complex and

C) at least one compound capable of forming metallocenium ions.

The invention also relates to a process for preparing such  
10 supported catalysts, copolymers suitable as support material and  
a process for the polymerization of olefins in the presence of a  
catalyst according to the present invention.

Supported transition metal catalysts have been known for a long  
15 time and are used, for example, for olefin polymerization. The  
activity and productivity of these catalysts depends very much on  
the method by which they are produced. As support materials for  
such transition metal catalysts, it is customary to use  
crosslinked polymers or inorganic support materials, for example  
20 silica gel. Examples of such supported catalysts are described,  
for example, in WO 94/28034, in EP-A 295 312 and in WO 98/01481.

When fixing metallocenes to the surface of inorganic materials  
and in the subsequent polymerization, some undesirable effects  
25 can occur. Thus, it is difficult to distribute the catalyst  
component homogeneously over the surface of the porous support  
material. During the course of the polymerization, fragmentation  
of the catalyst and the support material generally occurs. Owing  
to the inhomogeneous distribution of the catalyst components on  
30 the surface of the support, the fragmentation again forms  
inhomogeneous catalyst particles which can have an adverse effect  
on the polymerization products.

When the metallocenes are supported on crosslinked polymers, one  
35 frequently encounters the problem that, as a result of incomplete  
swelling of the crosslinked polymer particles, only an  
inhomogeneous distribution of the metallocenes on the support is  
once more achieved.

40 S.B. Roscoe, J.M. Fréchet, J.M. Walzer and A.J. Dias, Science  
280, 1998, pages 270-273, describe a supported catalyst in which  
a divinylbenzene-crosslinked, chloromethylated polystyrene was  
reacted in succession with a secondary amine, an ammonium salt of  
a weakly coordinating anion and an uncharged dialkyl metallocene.  
45 This gave a polymerization-active catalyst. However, at elevated  
polymerization temperatures, the polymer morphology obtained was

unsatisfactory and polymerization could only be carried out using hafnocenes.

A.G.M. Barrett and Y.R. de Miguel, Chem. Commun. 1998, pages 2079  
5 ff, disclosed a catalyst in which a peralkylated titanocene  
complex was covalently bound to a polystyrene support. The  
unpublished German Patent Application No. 19821949.0 likewise  
describes a process in which metallocene complexes are covalently  
bound to a polystyrene support. However, in the case of  
10 metallocenes having a more complicated structure, as are  
required, for example, for the stereoselective polymerization of  
propylene, the corresponding synthesis is very difficult or can  
no longer be carried out.

15 It is an object of the present invention to find supported  
catalysts which no longer have the disadvantages of the prior art  
and have a homogeneous distribution of the catalyst components on  
the support material, which can be prepared without any great  
difficulty using many different metallocene systems and which  
20 also give a good polymer morphology at an elevated polymerization  
temperature.

We have found that this object is achieved by the supported  
catalyst for olefin polymerization defined at the outset.

25 Furthermore, we have found a process for preparing such supported  
catalysts, copolymers suitable as support material and a process  
for the polymerization of olefins in the presence of a catalyst  
according to the present invention.

30 The supported catalyst of the present invention for olefin  
polymerization comprises as support material A) a copolymer  
comprising at least the monomer units I, II and III. Among these  
monomer units, the monomer unit I serves as basic framework of  
the support material. The monomer unit II allows crosslinking of  
35 the polymer chains by means of a Diels-Alder reaction of the  
cyclopentadienyl radicals. The monomer unit III introduces  
sufficient polarity into the copolymer A) for the active  
components B) and C) to be fixed to the support material, even  
though they are not covalently bound.

40 The radical  $R^1$  in the monomers I, II and III can in each case be  
hydrogen, a  $C_1$ - $C_4$ -alkyl group, i.e. methyl, ethyl or the various  
isomers of propyl or butyl, or phenyl. Preferably,  $R^1$  is in each  
case hydrogen or methyl and in particular hydrogen.

45

## 4

The radical  $R^2$  in the formula (I) is preferably substituted or unsubstituted phenyl, pyrenyl, naphthyl or alkenyl. Preferred monomers I are styrene, butadiene and isoprene.

- 5 In the formula (II), the variable  $A^1$  is a direct chemical bond or a substituted or unsubstituted phenylene group;  $A^1$  is preferably a direct chemical bond or a p-phenylene group.

- The substituents  $R^3$  in the formula (II) can be identical or  
10 different and are preferably hydrogen, methyl, ethyl or the various isomers of propyl or phenyl and are in particular hydrogen or methyl.

- The variable n of the formula (II) is preferably 0 or 1.  
15

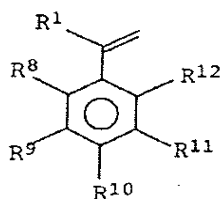
- The cyclopentadienyl radical in the formula (II) can be unsubstituted, in which case the radicals  $R^4$  to  $R^7$  are each hydrogen. However, it can also be monosubstituted to tetrasubstituted. Suitable substituents  $R^4$  to  $R^7$  are then  
20  $C_1$ - $C_{10}$ -alkyl groups, i.e. methyl, ethyl and the various isomers of propyl, butyl, pentyl, hexyl, heptyl, octyl, nonyl or decyl. Further suitable radicals  $R^4$  to  $R^7$  are substituted or unsubstituted phenyl radicals, in particular unsubstituted phenyl radicals. However, the cyclopentadienyl radicals in the formula  
25 (II) are particularly preferably unsubstituted.

- Particularly preferred monomer units II are those in which  $A^1$  is p-phenylene, p is 1 and  $R^3$  and  $R^4$  to  $R^7$  are each hydrogen or those in which  $A^1$  is a direct bond, p is 1,  $R^3$  are each methyl and  $R^4$  to  
30  $R^7$  are each hydrogen.

- The monomer units III are compounds which can be copolymerized with the monomers I and II or with monomers which can be converted into the monomer units I and II and have polar groups.  
35

- Preferred monomer units III are compounds of the formula (IIIa),

40



(IIIa)

45

5

where

$R^8$  to  $R^{12}$  are hydrogen,  $C_1$ - $C_{10}$ -alkyl, 5- to 7-membered cycloalkyl which may in turn bear  $C_1$ - $C_{10}$ -alkyl groups as substituents,  $C_6$ - $C_{15}$ -aryl or arylalkyl,

or adjacent radicals may in each case form a saturated or unsaturated ring having from 5 to 15 carbon atoms,

but at least one radical  $R^8$  to  $R^{12}$  is a group of the formula (IV),



where

$R^{13}$  are identical or different and are each hydrogen,  $C_1$ - $C_{10}$ -alkyl or substituted or unsubstituted phenyl,

$q$  is an integer from 0 to 8 and

$A^2$  is  $OR^{14}$ ,  $NR^{14}R^{15}$ ,  $PR^{14}R^{15}$ ,  $CN$ ,  $COOR^{14}$  or  $(O-(CH_2)_{q'})_{q''}-OR^{14}$ , where  $R^{14}$  and  $R^{15}$  are identical or different and are each hydrogen or  $C_1$ - $C_4$ -alkyl and  $q'$  is an integer from 1 to 5 and  $q''$  is an integer from 1 to 8.

Particularly preferred monomer units of the formula (IIIa) are those in which from one to three radicals  $R^8$  to  $R^{12}$  are a group of the formula (IV). In particular, preference is also given to monomers of the formula (IIIa) in which only one radical  $R^8$  to  $R^{12}$  is a group of the formula (IV), with the further radicals  $R^8$  to  $R^{12}$  then being hydrogen.

Preferred groups of the formula (IV) are those in which  $q$  is 0 or 1 and  $A^2$  is  $OR^{14}$  and is in particular methoxy or hydroxy.  $R^{13}$  is preferably hydrogen or methyl and  $q'$  is preferably 1, 2 or 3. Preference is also given to groups of the formula (IV) in which  $q$

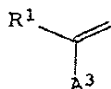
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is 2,  $R^{13}$  is hydrogen and  $A^2$  is hydroxy or  $(O-C_2H_4)_q-OH$ . Also preferred are groups in which  $A^2$  is CN.

For the radicals  $R^8$  to  $R^{12}$  which are not a group of the formula (IV), particular preference is given to hydrogen or  $C_1-C_4$ -alkyl, phenyl or tetramethylcyclopentadienyl.

Examples of suitable monomer units of the formula (IIIa) are p-methoxymethylstyrene, p-hydroxystyrene, p-methoxystyrene, (2-hydroxyethyl)styrene, trimethoxystyrene, (dimethylhydroxymethyl)styrene and (methoxymethyl) (methoxy)styrene.

Further preferred monomer units III are compounds of the formula (IIIb),



(IIIb)

where

$A^3$  is  $COOR^{16}$  or CN, where

$R^{16}$  is hydrogen or  $C_1-C_{10}$ -alkyl.

Here, mention may be made of, for example, acrylic esters, methacrylic esters, acrylonitrile and methacrylonitrile.

The monomer units I, II or III used in the copolymers A) can also in each case be mixtures of various compounds of the formulae (I), (II), (IIIa) and/or (IIIb). Any further olefinic comonomers can also be present in the copolymers (A) provided that they do not interfere in the synthesis of the copolymers. However, the copolymers (A) preferably contain only the monomer units I, II and III.

The ratios of the monomer units I, II and III can be varied within a wide range. It is usual to employ a larger proportion of I. The proportion of monomer units II in the total copolymer is advantageously from 3 to 30 mol%, based on the total mass of the copolymer, particularly preferably from 10 to 20 mol%. The proportion of monomer units III in the total copolymer is

preferably from 10 to 40 mol%, based on the total mass of the copolymer, particularly preferably from 20 to 30 mol%.

The copolymers A) can be prepared by copolymerization of 5 compounds of the formulae (I), (II) and (IIIa) and/or (IIIb) or of compounds which can be converted into the corresponding monomer units by polymer-analogous reactions. The copolymerization can be carried out in a customary manner known to those skilled in the art, for example by a free-radical or 10 anionic mechanism. The copolymers A) are preferably prepared by free-radical polymerization. The copolymers A) generally have a molar mass  $M_w$  (weight average) in the range from 15000 to 70000 g/mol, preferably from 30000 to 50000 g/mol. The width of the molar mass distribution  $M_n/M_w$  is generally from 2 to 3.

15

Although the monomer units I are usually introduced into the copolymers A) using monomers which already have the appropriate structural features, the monomer units II are normally introduced by polymerizing monomers II' which are then converted into the 20 monomer units II in a polymer-analogous reaction. In this case, the monomers II' have replaceable leaving groups via which the cyclopentadiene ring can be introduced into the monomer units II.

Suitable replaceable leaving groups are, for example, 25 nucleophilically replaceable leaving groups such as halogens, i.e. fluorine, chlorine, bromine or iodine, or further nucleophilically replaceable leaving groups with which those skilled in the art are familiar, e.g. tosylate, trifluoroacetate, acetate or azide. A preferred monomer II' is 30 p-(chloromethyl)styrene.

After the polymerization, the nucleophilically replaceable leaving groups of the monomers II' can then be reacted with a cyclopentadienyl compound by various methods with which those 35 skilled in the art are familiar. For example, the cyclopentadiene compound can be converted into the cyclopentadienyl anion by means of a strong base such as butyllithium or sodium hydride or by means of an elemental alkali metal, for example sodium. This cyclopentadienyl anion can then replace the nucleophilically 40 replaceable leaving group in a nucleophilic substitution reaction.

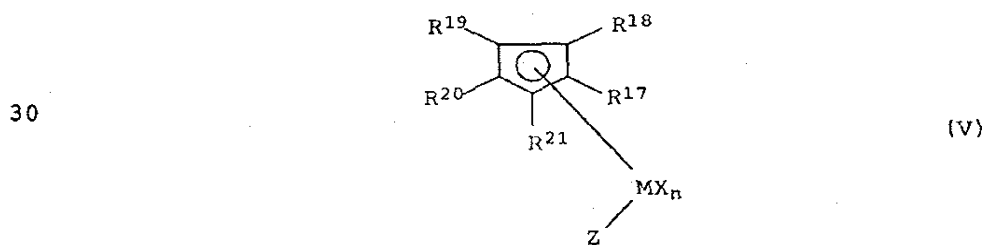
It is also possible to use monomers II' having leaving groups which can be converted into metal-containing functional groups 45 after the polymerization. Examples of appropriate metal-containing functional groups are  $-Li$ ,  $-MgX^4$ , where  $X^4$  is halogen, i.e. fluorine, chlorine, bromine or iodine. Examples of

such monomers II' are p-halostyrenes, preferably p-bromostyrene, in which the halogen can be replaced by the metal-containing functional group. It is then possible to react the resulting organometallic compound with a fulvene compound, thus forming 5 monomer units II.

Suitable fulvene compounds bear two identical or different radicals C<sub>1</sub>-C<sub>4</sub>-alkyl or substituted or unsubstituted phenyl on the methylene carbon; preferred substituents are methyl, ethyl or the 10 various isomers of propyl or phenyl and in particular methyl. A particularly preferred fulvene IIIa is dimethyl fulvene.

Monomer units III can be introduced into the copolymers A) by the use of monomers having an appropriate structure, for example 15 those of the formula (IIIb). However, it is here also possible to polymerize monomer units III' and then to convert these into monomer units III by polymer-analogous reactions. For example, halogen-containing monomers III' such as chloromethylstyrene can be converted into monomer units III containing methoxy groups, 20 for example methoxymethylstyrene, by reaction with a methoxide.

In addition, the supported catalysts of the present invention for olefin polymerization further comprise at least one metallocene complex B). Suitable metallocene complexes are, in particular, 25 those of the formula (V)



35 where the substituents and indices have the following meanings:

- |    |  |
|----|--|
| M  | is titanium, zirconium, hafnium, vanadium, niobium, tantalum or chromium or an element of transition group III of the Periodic Table and the lanthanides,  |
| 40 |  |
| X  | is fluorine, chlorine, bromine, iodine, hydrogen, C <sub>1</sub> -C <sub>10</sub> -alkyl, C <sub>6</sub> -C <sub>15</sub> -aryl, alkylaryl having from 1 to 10 carbon atoms in the alkyl part and from 6 |
| 45 |  |



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to 20 carbon atoms in the aryl part,  $-OR^{22}$  or  $-NR^{22}R^{23}$ ,

n is 1, 2 or 3, where n corresponds to the valence of M minus 2,

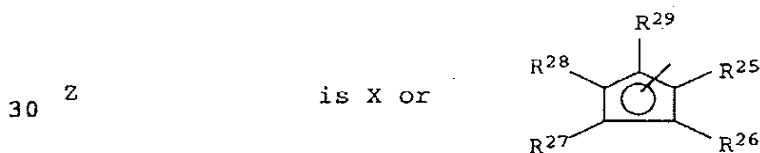
where

$R^{22}$  and  $R^{23}$  are  $C_1$ - $C_{10}$ -alkyl,  $C_6$ - $C_{15}$ -aryl, alkylaryl, arylalkyl, fluoroalkyl or fluoroaryl each having from 1 to 10 carbon atoms in the alkyl radical and from 6 to 20 carbon atoms in the aryl radical and

the radicals X are identical or different,

$R^{17}$  to  $R^{21}$  are hydrogen,  $C_1$ - $C_{10}$ -alkyl, 5- to 7-membered cycloalkyl which may in turn bear  $C_1$ - $C_{10}$ -alkyl groups as substituents,  $C_6$ - $C_{15}$ -aryl or arylalkyl, where two adjacent radicals may together form a saturated or unsaturated cyclic group having from 4 to 15 carbon atoms, or  $Si(R^{24})_3$  where

$R^{24}$  can be  $C_1$ - $C_{10}$ -alkyl,  $C_3$ - $C_{10}$ -cycloalkyl or  $C_6$ - $C_{15}$ -aryl and



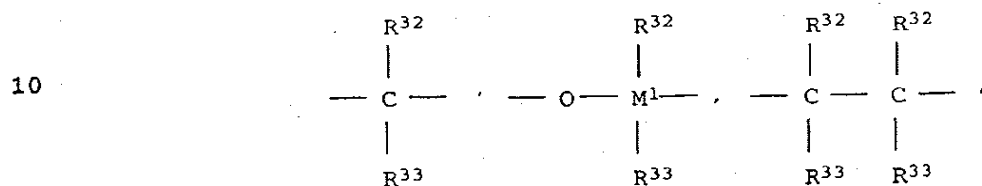
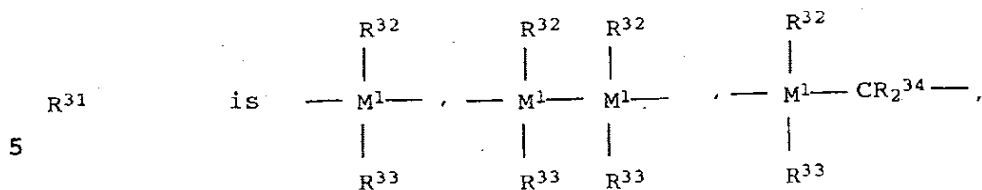
where the radicals

$R^{25}$  to  $R^{29}$  are hydrogen,  $C_1$ - $C_{10}$ -alkyl, 5- to 7-membered cycloalkyl which may in turn bear  $C_1$ - $C_{10}$ -alkyl groups as substituents,  $C_6$ - $C_{15}$ -aryl or arylalkyl and two adjacent radicals may also together form a saturated or unsaturated cyclic group having from 4 to 15 carbon atoms, or  $Si(R^{30})_3$  where

$R^{30}$  is  $C_1$ - $C_{10}$ -alkyl,  $C_3$ - $C_{10}$ -cycloalkyl or  $C_6$ - $C_{15}$ -aryl,

or the radicals  $R^{20}$  and Z together form an  $-R^{31}-A-$  group in which

10



15  $= BR^{32}, = AlR^{32}, -Ge-, -Sn-, -O-, -S-, = SO, = SO_2,$   
 $= NR^{32}, = CO, = PR^{32} \text{ or } = P(O)R^{32},$

where

20  $R^{32}, R^{33}$  and  $R^{34}$  are identical or different and are each a hydrogen atom, a halogen atom, a  $C_1$ - $C_{10}$ -alkyl group, a  $C_1$ - $C_{10}$ -fluoroalkyl group, a  $C_6$ - $C_{10}$ -fluoroaryl group, a  $C_6$ - $C_{10}$ -aryl group, a  $C_1$ - $C_{10}$ -alkoxy group, a  $C_2$ - $C_{10}$ -alkenyl group, a  $C_7$ - $C_{40}$ -arylalkyl group, a  $C_8$ - $C_{40}$ -arylalkenyl group or a  $C_7$ - $C_{40}$ -alkylaryl group or two adjacent radicals together with the atoms connecting them form a saturated or unsaturated ring having from 4 to 15 carbon atoms, and

30  $M^1$  is silicon, germanium or tin,

A is  $-O-$ ,  $-S-$ ,  $\begin{array}{c} \diagup \\ \diagdown \end{array} NR^{35}$  or  $\begin{array}{c} \diagup \\ \diagdown \end{array} PR^{35}$  where

35  $R^{35}$  is  $C_1$ - $C_{10}$ -alkyl,  $C_6$ - $C_{15}$ -aryl,  $C_3$ - $C_{10}$ -cycloalkyl,  $C_7$ - $C_{18}$ -alkylaryl or  $Si(R^{36})_3$ ,

40  $R^{36}$  is hydrogen,  $C_1$ - $C_{10}$ -alkyl,  $C_6$ - $C_{15}$ -aryl, which may in turn bear  $C_1$ - $C_4$ -alkyl groups as substituents or  $C_3$ - $C_{10}$ -cycloalkyl

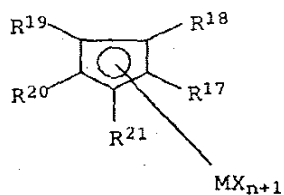
or the radicals  $R^{20}$  and  $R^{28}$  together form an  $-R^{31}-$  group.

45 The radicals X in the formula (V) are preferably identical.

11

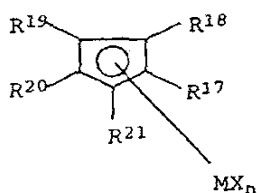
Among the metallocene complexes of the formula (V), preference is given to

5



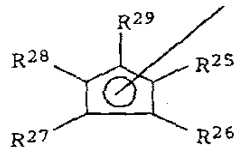
(Va),

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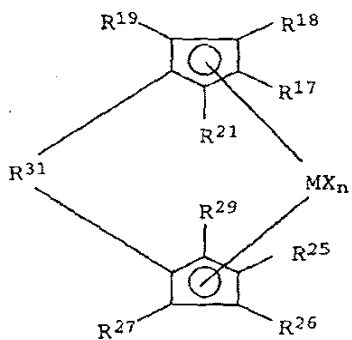
(Vb),

15



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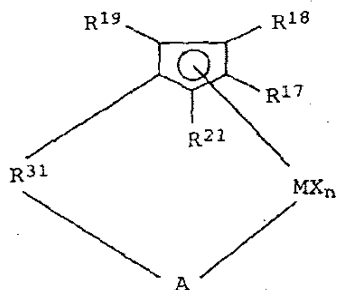
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(Vc) and

30

35



(Vd)

40

45

## 12

Among the compounds of the formula (Va), particular preference is given to those in which

- M is titanium, zirconium or hafnium,  
5 X is chlorine, C<sub>1</sub>-C<sub>4</sub>-alkyl or phenyl,  
n is 2 and  
10 R<sup>17</sup> to R<sup>21</sup> are hydrogen or C<sub>1</sub>-C<sub>4</sub>-alkyl.

Among the compounds of the formula (Vb), preference is given to those in which

- 15 M is titanium, zirconium or hafnium,  
X is chlorine, C<sub>1</sub>-C<sub>4</sub>-alkyl or phenyl,  
n is 2,  
20 R<sup>17</sup> to R<sup>21</sup> are hydrogen, C<sub>1</sub>-C<sub>4</sub>-alkyl or Si(R<sup>24</sup>)<sub>3</sub> and  
R<sup>25</sup> to R<sup>29</sup> are hydrogen, C<sub>1</sub>-C<sub>4</sub>-alkyl or Si(R<sup>30</sup>)<sub>3</sub>.  
25 Particularly suitable compounds of the formula (Vb) are those in which the cyclopentadienyl radicals are identical.

Examples of particularly useful compounds are:

- 30 bis(cyclopentadienyl)zirconium dichloride,  
bis(pentamethylcyclopentadienyl)zirconium dichloride,  
bis(methylcyclopentadienyl)zirconium dichloride,  
bis(ethylcyclopentadienyl)zirconium dichloride,  
bis(n-butylcyclopentadienyl)zirconium dichloride and  
35 bis(trimethylsilylcyclopentadienyl)zirconium dichloride  
and also the corresponding dimethylzirconium compounds.

Among the compounds of the formula (Vc), particularly suitable compounds are ones in which

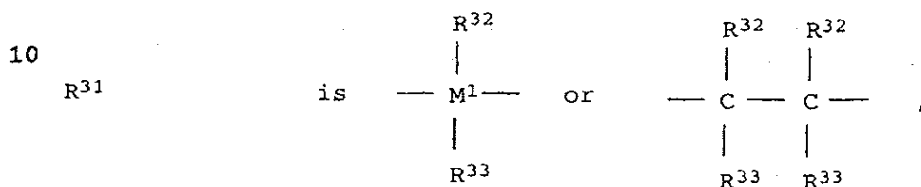
- 40 R<sup>17</sup> and R<sup>25</sup> are identical and are hydrogen or C<sub>1</sub>-C<sub>10</sub>-alkyl groups,  
R<sup>21</sup> and R<sup>29</sup> are identical and are hydrogen or methyl, ethyl,  
45 isopropyl or tert-butyl groups,  
R<sup>19</sup> and R<sup>27</sup> are C<sub>1</sub>-C<sub>4</sub>-alkyl and

13

$R^{18}$  and  $R^{26}$  are hydrogen

or

5 two adjacent radicals  $R^{18}$  and  $R^{19}$  or  $R^{26}$  and  $R^{27}$  together form a saturated or unsaturated cyclic group having from 4 to 12 carbon atoms,



15

M is titanium, zirconium or hafnium and

X is chlorine,  $C_1$ - $C_4$ -alkyl or phenyl.

20 Examples of particularly useful complexes are:

- dimethylsilanediylbis(cyclopentadienyl)zirconium dichloride,
- dimethylsilanediylbis(indenyl)zirconium dichloride,
- dimethylsilanediylbis(tetrahydroindenyl)zirconium dichloride,
- 25 ethylenebis(cyclopentadienyl)zirconium dichloride,
- ethylenebis(indenyl)zirconium dichloride,
- ethylenebis(tetrahydroindenyl)zirconium dichloride,
- tetramethylethylene-9-fluorenylcyclopentadienylzirconium dichloride,
- 30 dimethylsilanediylbis(3-tert-butyl-5-methylcyclopentadienyl)-zirconium dichloride,
- dimethylsilanediylbis(3-tert-butyl-5-ethylcyclopentadienyl)-zirconium dichloride,
- dimethylsilanediylbis(2-methylindenyl)zirconium dichloride,
- 35 dimethylsilanediylbis(2-isopropylindenyl)zirconium dichloride,
- dimethylsilanediylbis(2-tert-butylindenyl)zirconium dichloride,
- diethylsilanediylbis(2-methylindenyl)zirconium dibromide,
- dimethylsilanediylbis(3-methyl-5-methylcyclopentadienyl)-zirconium dichloride,
- 40 dimethylsilanediylbis(3-ethyl-5-isopropylcyclopentadienyl)-zirconium dichloride,
- dimethylsilanediylbis(2-ethylindenyl)zirconium dichloride,
- dimethylsilanediylbis[3,3'-(2-methylbenzindenyl)]-zirconium dichloride
- 45 dimethylsilanediylbis[3,3'-(2-ethylbenzindenyl)]zirconium dichloride,
- methylphenylsilanediylbis[3,3'-(2-ethylbenzindenyl)]-

14

zirconium dichloride,  
 methylphenylsilanediylbis[3,3'-(2-methylbenzindenyl)]zirconium  
 dichloride,  
 diphenylsilanediylbis[3,3'-(2-methylbenzindenyl)]zirconium  
 5 dichloride,  
 diphenylsilanediylbis[3,3'-(2-ethylbenzindenyl)]zirconium  
 dichloride, and  
 diphenylsilanediylbis(2-methylindenyl)hafnium dichloride

10 and also the corresponding dimethyl zirconium compounds.

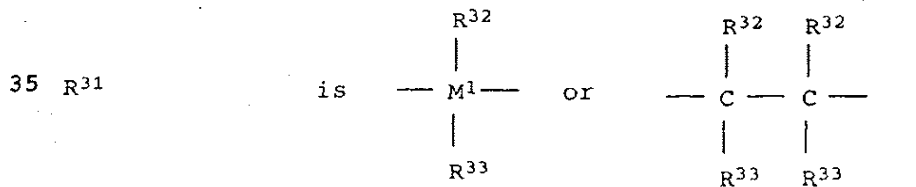
Further examples of suitable complexes are:

dimethylsilanediylbis(2-methyl-4-phenylindenyl)zirconium  
 15 dichloride,  
 dimethylsilanediylbis(2-methyl-4-(p-tert-butylphenyl)indenyl)-  
 zirconium dichloride,  
 dimethylsilanediylbis(2-methyl-4-naphthylindenyl)zirconium  
 dichloride,  
 20 dimethylsilanediylbis(2-methyl-4-isopropylindenyl)zirconium  
 dichloride and  
 dimethylsilanediylbis(2-methyl-4,6-diisopropylindenyl)zirconium  
 dichloride and also the corresponding dimethyl zirconium  
 compounds.

25

Among the compounds of the formula (Vd), particularly suitable  
 compounds are those in which

M is titanium or zirconium,  
 30 X is chlorine, C<sub>1</sub>-C<sub>4</sub>-alkyl or phenyl,



40

A is  $\text{--- O ---}$ ,  $\text{--- S ---}$ ,  $\text{--- NR}^{35}$

and

45

15

R<sup>17</sup> to R<sup>19</sup> and R<sup>21</sup> are hydrogen, C<sub>1</sub>-C<sub>10</sub>-alkyl, C<sub>3</sub>-C<sub>10</sub>-cycloalkyl, C<sub>6</sub>-C<sub>15</sub>-aryl or Si(R<sup>24</sup>)<sub>3</sub>, or two adjacent radicals form a cyclic group having from 4 to 12 carbon atoms.

5

Such complexes can be synthesized by methods known per se, with preference being given to the reaction of the appropriately substituted, cyclic hydrocarbon anions with halides of titanium, zirconium, hafnium, vanadium, niobium or tantalum.

10

Examples of appropriate preparative methods are described, for example, in the Journal of Organometallic Chemistry, 369 (1989), 359-370.

15 As component B), it is also possible for mixtures of various metallocene complexes to be present in the supported catalysts of the present invention.

In addition, the supported catalysts of the present invention for  
20 olefin polymerization further comprise at least one compound C) capable of forming metallocenium ions. Suitable compounds C) capable of forming metallocenium ions are, for example, strong uncharged Lewis acids, ionic compounds having Lewis acid cations or ionic compounds containing Brønsted acids as cations.

25

As strong, uncharged Lewis acids, preference is given to compounds of the formula (VI)



30 where

M<sup>2</sup> is an element of main group III of the Periodic Table, in particular B, Al or Ga, preferably B,

35 X<sup>1</sup>, X<sup>2</sup> and X<sup>3</sup> are hydrogen, C<sub>1</sub>-C<sub>10</sub>-alkyl, C<sub>6</sub>-C<sub>15</sub>-aryl, alkylaryl, arylalkyl, haloalkyl or haloaryl each having from 1 to 10 carbon atoms in the alkyl radical and from 6 to 20 carbon atoms in the aryl radical or fluorine, chlorine, bromine or iodine,  
40 in particular haloaryls, preferably pentafluorophenyl.

Particular preference is given to compounds of the formula (VI) in which X<sup>1</sup>, X<sup>2</sup> and X<sup>3</sup> are identical, preferably  
45 tris(pentafluorophenyl)borane.

## 16

Suitable ionic compounds having Lewis acid cations are compounds of the formula (VII)



5

where

Y

is an element of main groups I to VI or transition groups I to VIII of the Periodic Table,

10

 $Q_1$  to  $Q_z$ 

are singly negatively charged groups such as  $C_1$ - $C_{28}$ -alkyl,  $C_6$ - $C_{15}$ -aryl, alkylaryl, arylalkyl, haloalkyl, haloaryl each having from 6 to 20 carbon atoms in the aryl moiety and from 1 to 28 carbon atoms in the alkyl moiety,  $C_3$ - $C_{10}$ -cycloalkyl, which may bear  $C_1$ - $C_{10}$ -alkyl groups as substituents, halogen,  $C_1$ - $C_{28}$ -alkoxy,  $C_6$ - $C_{15}$ -aryloxy, silyl or mercaptyl groups,

15

20

a

is an integer from 1 to 6,

z

is an integer from 0 to 5 and

25 d

corresponds to the difference  $a-z$ , but  $d$  is greater than or equal to 1.

Particularly suitable Lewis acid cations are carbonium cations, oxonium cations and sulfonium cations and also cationic transition metal complexes. In particular, mention may be made of the triphenylmethyl cation, the silver cation and the 1,1'-dimethylferrocenyl cation. They preferably have non-coordinating counterions, in particular boron compounds as are also mentioned in WO 91/09882, preferably tetrakis(pentafluorophenyl)borate.

30

35

Ionic compounds having Brønsted acids as cations and preferably likewise non-coordinating counterions are mentioned in WO 91/09882; the preferred cation is N,N-dimethylanilinium.

40

The amount of strong, uncharged Lewis acids, ionic compounds having Lewis acid cations or ionic compounds having Brønsted acids as cations is preferably from 0.1 to 10 equivalents, based on the metallocene complex B).

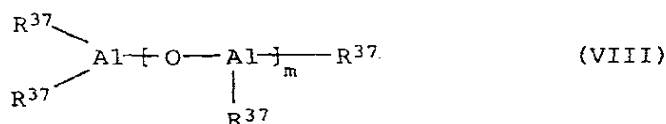
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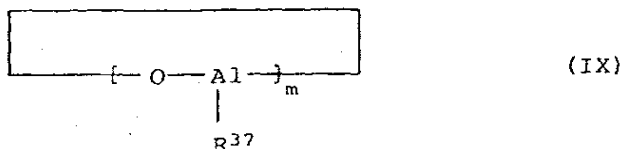
17

Particularly useful compounds C) capable of forming metallocenium ions are open-chain or cyclic aluminoxane compounds of the formula (VIII) or (IX)

5



10



15

where  $\text{R}^{37}$  is a  $\text{C}_1\text{-C}_{10}$ -alkyl group, preferably a methyl or ethyl group, and  $m$  is an integer from 5 to 30, preferably from 10 to 25.

20 The preparation of these oligomeric aluminoxane compounds is usually carried out by reacting a solution of trialkylaluminum with water and is described, for example, in EP-A 284 708 and US-A 4 794 096.

25 In general, the oligomeric aluminoxane compounds obtained in this way are in the form of mixtures of both linear and cyclic chain molecules of various lengths, so that  $m$  should be regarded as a mean value. The aluminoxane compounds can also be present in admixture with other metal alkyls, preferably aluminum alkyls.

30

It has been found to be advantageous to use the metallocene complexes B) and the oligomeric aluminoxane compounds of the formulae (VIII) and (IX) in such amounts that the atomic ratio of aluminum from the oligomeric aluminoxane compounds to the transition metal from the metallocene complexes is in the range from 10:1 to  $10^6$ :1, in particular in the range from 10:1 to  $10^4$ :1.

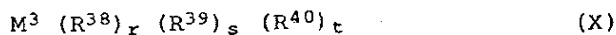
Furthermore, it is possible to use aryloxyaluminoxanes as described in US-A 5 391 793, aminoaluminoxanes as described in US-A 5 371 260, aminoaluminoxane hydrochlorides as described in EP-A 633 264, siloxyaluminoxanes as described in EP-A 621 279 or mixtures thereof as component C) in place of the aluminoxane compounds of the formula (VIII) or (IX).

45 Preferably, both the metallocene complexes B) and the compounds C) capable of forming metallocenium ions are used in solution, with particular preference being given to aromatic hydrocarbons

18

having from 6 to 20 carbon atoms, in particular xylenes and toluene.

The supported catalysts of the present invention for olefin polymerization can further comprise, as additional component D), one or more metal compounds of the formula (X)



10

where

$M^3$  is an alkali metal, an alkaline earth metal or a metal of main group III of the Periodic Table, i.e. boron, aluminum, gallium, indium or thallium,

15

$R^{38}$  is hydrogen,  $C_1$ - $C_{10}$ -alkyl,  $C_6$ - $C_{15}$ -aryl, alkylaryl or arylalkyl each having from 1 to 10 carbon atoms in the alkyl part and from 6 to 20 carbon atoms in the aryl part,

20

$R^{39}$  and  $R^{40}$  are hydrogen, halogen,  $C_1$ - $C_{10}$ -alkyl,  $C_6$ - $C_{15}$ -aryl, alkylaryl, arylalkyl or alkoxy each having from 1 to 10 carbon atoms in the alkyl part and from 6 to 20 carbon atoms in the aryl part,

25

$r$  is an integer from 1 to 3

30 and

$s$  and  $t$  are integers from 0 to 2, where the sum  $r+s+t$  corresponds to the valence of  $M^3$ .

35 Among the metal compounds of the formula (X), preference is given to those in which

$M^3$  is lithium, magnesium or aluminum and

40  $R^{39}$  and  $R^{40}$  are  $C_1$ - $C_{10}$ -alkyl.

Particularly preferred metal compounds of the formula (X) are n-butyllithium, n-butyl-n-octylmagnesium, n-butyl-n-heptylmagnesium, tri-n-hexylaluminum,

45 triisobutylaluminum, triethylaluminum and trimethylaluminum.

## 19

If a metal compound D) is used, it is preferably present in the catalyst system in such an amount that the molar ratio of  $M^3$  from formula (X) to transition metal M from formula (V) is from 800:1 to 1:1, in particular from 500:1 to 50:1.

5

The supported catalysts are preferably prepared by first preparing a copolymer A) by polymerization in solution in a suitable solvent, e.g. an aromatic solvent such as toluene, or copolymerizing appropriate monomers and then converting the resulting copolymer into the copolymer A) by polymer-analogous reaction in solution. The further steps are then carried out using this solution. Alternatively, a separately prepared copolymer A) which is then present, for example, as a solid is dissolved in a suitable solvent.

15

B) and C) are then added to this solution of the copolymer A). The order of addition is in principle immaterial. However, preference is given to first mixing B) and C) with one another in solution and then adding this mixture to the solution of the copolymer A).

20

The compounds of the formula (X) used as component D) can be added to the copolymer A) prior to the addition of the metallocene complexes B) and the compounds C) capable of forming metallocenium ions. In particular, such a compound of the formula (X) is added prior to the components B) and C) when the copolymer A) contains acidic hydrogen atoms in the monomer units III. However, it is also possible to mix the same or other compounds of the formula (X) first with the metallocene complexes B) and then to add these mixtures to the copolymer A).

30

Since the copolymer A) is brought into contact with the metallocene complexes B) and the compounds C) capable of forming metallocenium ions in a homogeneous solution, a homogeneous distribution of the active components is ensured by this means.

35

Before or after addition of the metallocene complexes B) and the compounds C) capable of forming metallocenium ions to the copolymer A), the latter is preferably crosslinked in the solution at from 0 to 150°C, in particular from 50 to 100°C, by means of a Diels-Alder reaction of the cyclopentadienyl radicals. However, the resulting crosslinked polymer is swollen to such an extent that it behaves like a homogeneous solution.

45

## 20

In general, addition of the components B) and C) to A) forms a solid which, after removal of the solvent, is in finely divided form, preferably as particles having mean particle diameters in the range from 5 to 200  $\mu\text{m}$ , in particular from 20 to 100  $\mu\text{m}$ .

5

After isolation, the resulting crosslinked polymer containing the bound metallocene complexes is largely insoluble in organic solvents and in this form is suitable for use in polymerization reactions in the gas phase or in suspension.

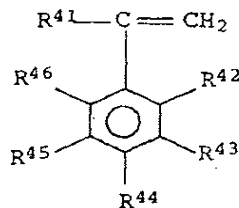
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Under thermal stress, i.e., for example, during the polymerization reaction or during subsequent work-up steps, for instance during an extrusion, this insoluble supported catalyst can fragment in a retro-Diels-Alder reaction to form the soluble copolymer chains again. The supported catalyst which has been fragmented in this way can as a result become particularly homogeneously distributed in the polymer formed.

Like the supported catalysts of the present invention, the copolymers comprising the monomer units I, II and IIIa have also not been known hitherto. These copolymers can be used as support material for a wide variety of metallocene catalysts.

The supported catalysts of the present invention are useful, for example, for the polymerization of olefins and particularly for the polymerization of  $\alpha$ -olefins, i.e. hydrocarbons having terminal double bonds. Suitable monomers may be functionalized olefinically unsaturated compounds such as ester or amide derivatives of acrylic or methacrylic acid, for example acrylates, methacrylates or acrylonitrile. Preference is given to non polar olefinic compounds, including aryl-substituted  $\alpha$ -olefins. Particularly preferred  $\alpha$ -olefins are linear or branched  $\text{C}_2$ - $\text{C}_{12}$ -alk-1-enes, in particular linear  $\text{C}_2$ - $\text{C}_{10}$ -alk-1-enes such as ethylene, propylene, 1-butene, 1-pentene, 1-hexene, 1-heptene, 1-octene, 1-nonene, 1-decene or 4-methyl-1-pentene, or unsubstituted or substituted vinyl aromatic compounds of the formula (XI)

40



(XI)

45

where the substituents have the following meanings:

R<sup>41</sup> is hydrogen or C<sub>1</sub>- to C<sub>4</sub>-alkyl, preferably hydrogen;

5 R<sup>42</sup> to R<sup>46</sup> are, independently of one another, hydrogen, C<sub>1</sub>-C<sub>12</sub>-alkyl, C<sub>6</sub>-C<sub>18</sub>-aryl or halogen or two adjacent radicals together form a group having from 4 to 15 carbon atoms; preferably hydrogen, C<sub>1</sub>- to C<sub>4</sub>-alkyl, chlorine, phenyl, biphenyl, naphthalene or anthracene  
10 or two adjacent radicals together form a group having from 4 to 12 carbon atoms so as to give, for example, naphthalene derivatives or anthracene derivatives as compounds of the formula V.

15 Examples of preferred vinyl aromatic monomers are styrene, p-methylstyrene, p-chlorostyrene, 2,4-dimethylstyrene, 4-vinylbiphenyl, vinylnaphthalene or vinylanthracene.

It is also possible to polymerize mixtures of various  $\alpha$ -olefins.

20 In particular, the supported catalysts of the present invention can be used in various processes for the polymerization of ethylene, propylene or styrene. Apart from the homopolymerization of ethylene, propylene or styrene, the supported catalysts of the  
25 present invention are particularly suitable for copolymerization since the catalysts lead to uniform incorporation of the comonomer into the polymer and generally to narrow molar mass distributions. As comonomers in ethylene polymerization, preference is given to using C<sub>3</sub>- to C<sub>8</sub>- $\alpha$ -olefins, in particular  
30 butene, pentene, hexene and/or octene. Preferred comonomers in propylene polymerization are ethylene and/or butene.

The polymerization process of the present invention is generally carried out at from -50 to 300°C, preferably from 0 to 150°C, and  
35 at pressures in the range from 0.5 to 3000 bar, preferably in the range from 1 to 80 bar.

The polymerization can be carried out in solution, in suspension, in liquid monomers or in the gas phase. The polymerization is  
40 preferably carried out in liquid monomers, in suspension or by a gas-phase process, with preference being given to processes in a stirred gas phase or in a gas-phase fluidized bed.

The supported catalysts of the present invention have, in  
45 particular, a homogeneous distribution of the catalyst components on the support material and can be prepared without any great effort with many different metallocene systems. The active

## 22

component is strongly bound to the support in these supported catalysts, and a good polymer morphology is obtained even at an elevated polymerization temperature.

## 5 Examples

## Example 1

Preparation of a styrene-p-chloromethylstyrene-p-bromostyrene  
10 copolymer comprising 30 mol% of chloromethylstyrene, 10 mol% of bromostyrene and 60 mol% of styrene

6 mmol (916 mg) of p-chloromethylstyrene, 2 mmol (366 mg) of p-bromostyrene and 12 mmol (1.25 g) of styrene were dissolved in  
15 2.5 ml of toluene and polymerized using 50 mg of AIBN at 70°C for 24 hours. The solution was diluted to 25 ml with dichloromethane and the polymer was precipitated from 250 ml of methanol and dried under reduced pressure.

20 Yield: 72%.

The p-chloromethyl content could be determined by means of <sup>1</sup>H-NMR spectroscopy and was 30 mol%.

25 <sup>1</sup>H-NMR (CDCl<sub>3</sub>, 250 MHz) [ppm]: 4.49 (bs, 2H, Ph-CH<sub>2</sub>-Cl)

## Example 2

Preparation of a styrene-p-methoxymethylstyrene-p-bromostyrene  
30 copolymer

1 g of the copolymer obtained in Example 1 (comprising 2.37 mmol of p-chloromethylstyrene) was dissolved in a mixture of 25 ml of methanol and 50 ml of THF and, after addition of 1280 mg (23.7  
35 mmol) of sodium methoxide, was heated at 60°C for 24 hours. This converted the chloromethyl groups into methoxymethyl units. Sodium chloride was precipitated during the reaction. The solution was evaporated to 10 ml and the polymer was precipitated from 100 ml of methanol and dried under reduced pressure.

40

Yield: 88%.

The methoxymethyl content could be determined by means of <sup>1</sup>H-NMR spectroscopy and was 30 mol%.

45

## 23

<sup>1</sup>H-NMR (CDCl<sub>3</sub>, 250 MHz) [ppm]: 4.35 (bs, 2H, Ph-CH<sub>2</sub>-O-), 3.32 (bs, 3H, -O-CH<sub>3</sub>)

## Example 3

5

## Preparation of a cyclopentadiene-containing copolymer

500 mg (0.4 mmol of p-bromostyrene) of the copolymer obtained in Example 2 were dissolved in 50 ml of THF and cooled to -78°C.

- 10 0.27 ml (0.4 mmol) of an n-butyllithium solution (1.5 M in hexane) was added dropwise to this solution. After 10 minutes, 0.8 ml (0.4 mmol) of a dimethylfulvene solution (0.5 M in THF) was added. After a further 10 minutes, cooling was removed and the mixture was warmed to room temperature. The solution was
- 15 evaporated to 10 ml and the polymer was precipitated from 100 ml of methanol and dried under reduced pressure.

Yield: 92%.

## 20 Example 4

## Preparation of supported catalysts

## Example 4.1

25

Application of [dimethyl-bis(2-methylbenzindenyl)silyl]zirconium dichloride to a support

- 100 mg of the copolymer obtained in Example 3 were heated at 80°C
- 30 in 5 ml of toluene for 24 hours. The viscosity of the solution increased noticeably. After cooling to room temperature, 1 ml of a solution of 55.2 mg (0.1 mmol) of [dimethyl-bis(2-methylbenzindenyl)silyl]zirconium dichloride in 20 ml (32 mmol of Al) of methylaluminoxane (1.6 M in toluene) was
- 35 added. This resulted in precipitation of the support together with the colored metallocene. The precipitation was completed by addition of 100 ml of hexane. The supernatant, only slightly colored solution was removed by means of a syringe and the catalyst was washed once more with hexane. After the solvent had
- 40 been removed again, the catalyst was dried in a high vacuum while stirring with a magnetic stirrer. The polymer was thus ground to a fine, free-flowing powder.

## 24

## Example 4.2

Application of [dimethyl-bis(2-methylindenyl)silyl]zirconium dichloride to a support

5

The procedure of Example 4.1 was repeated, but 1 ml of a solution of 47.6 mg (0.1 mmol) of

[dimethyl-bis(methylindenyl)silyl]zirconium dichloride in 20 ml (32 mmol of Al) of methylaluminoxane (1.6 M in toluene) was added

10 to the copolymer obtained in Example 3. This gave a free-flowing, orange catalyst powder.

## Example 4.3

15 Application of

[dimethyl-bis(2-methyl-4-phenylindenyl)silyl]zirconium dichloride to a support

The procedure of Example 4.1 was repeated, but 1 ml of a solution

20 of 60.1 mg (0.1 mmol) of

[dimethyl-bis(2-methyl-4-phenylindenyl)silyl]zirconium dichloride in 20 ml (32 mmol of Al) of methylaluminoxane (1.6 M in toluene) was added to the copolymer obtained in Example 3. This gave a free-flowing, pink catalyst powder.

25

## Example 5

Polymerization of propylene

30 Example 5.1

In a 1 l autoclave, 400 ml of hexane together with 0.8 ml of a triisobutylaluminum solution (1 M in hexane) were heated to 50°C and stirred for 15 minutes. 2.5 ml of methylaluminoxane solution

35 (1.6 M in toluene) and in each case 50 mg of the supported catalyst prepared in Example 4.1 were added thereto and the mixture was stirred for another 15 minutes. A propene pressure of 5 bar was then slowly built up. The polymerization was carried out at constant pressure for a time of 30 minutes. A polymer

40 having a good morphology was obtained. In particular, the absence of fine dust indicated that no active component was leached from the supported catalyst.

The polymerization results are shown in the Table.

45



## 25

## Example 5.2

In a 1 l autoclave, 400 ml of hexane together with 0.8 ml of a triisobutylaluminum solution (1 M in hexane) were heated to 50°C and stirred for 15 minutes. 2.5 ml of methylaluminoxane solution (1.6 M in toluene) and in each case 50 mg of the supported catalyst prepared in Example 4.2 were added thereto and the mixture was stirred for another 15 minutes. A propene pressure of 5 bar was then slowly built up. The polymerization was carried out at constant pressure for a time of 30 minutes. A polymer having a good morphology was obtained. In particular, the absence of fine dust indicated that no active component was leached from the supported catalyst.

15 The polymerization results are shown in the Table.

## Example 5.3

In a 1 l autoclave, 400 ml of hexane together with 0.8 ml of a triisobutylaluminum solution (1 M in hexane) were heated to 50°C and stirred for 15 minutes. 2.5 ml of methylaluminoxane solution (1.6 M in toluene) and in each case 50 mg of the supported catalyst prepared in Example 4.3 were added thereto and the mixture was stirred for another 15 minutes. A propene pressure of 5 bar was then slowly built up. The polymerization was carried out at constant pressure for a time of 30 minutes. A polymer having a good morphology was obtained. In particular, the absence of fine dust indicated that no active component was leached from the supported catalyst.

30

The polymerization results are shown in the Table.

Table

35

Example	Yield [g]	Activity [kg PP/ (mol Zr h bar)]	Productivity [g PP/ (g cat. h bar)]
5.1.	11.2	3300	90
5.2.	23.6	6800	190
5.3.	27.4	8200	220

45